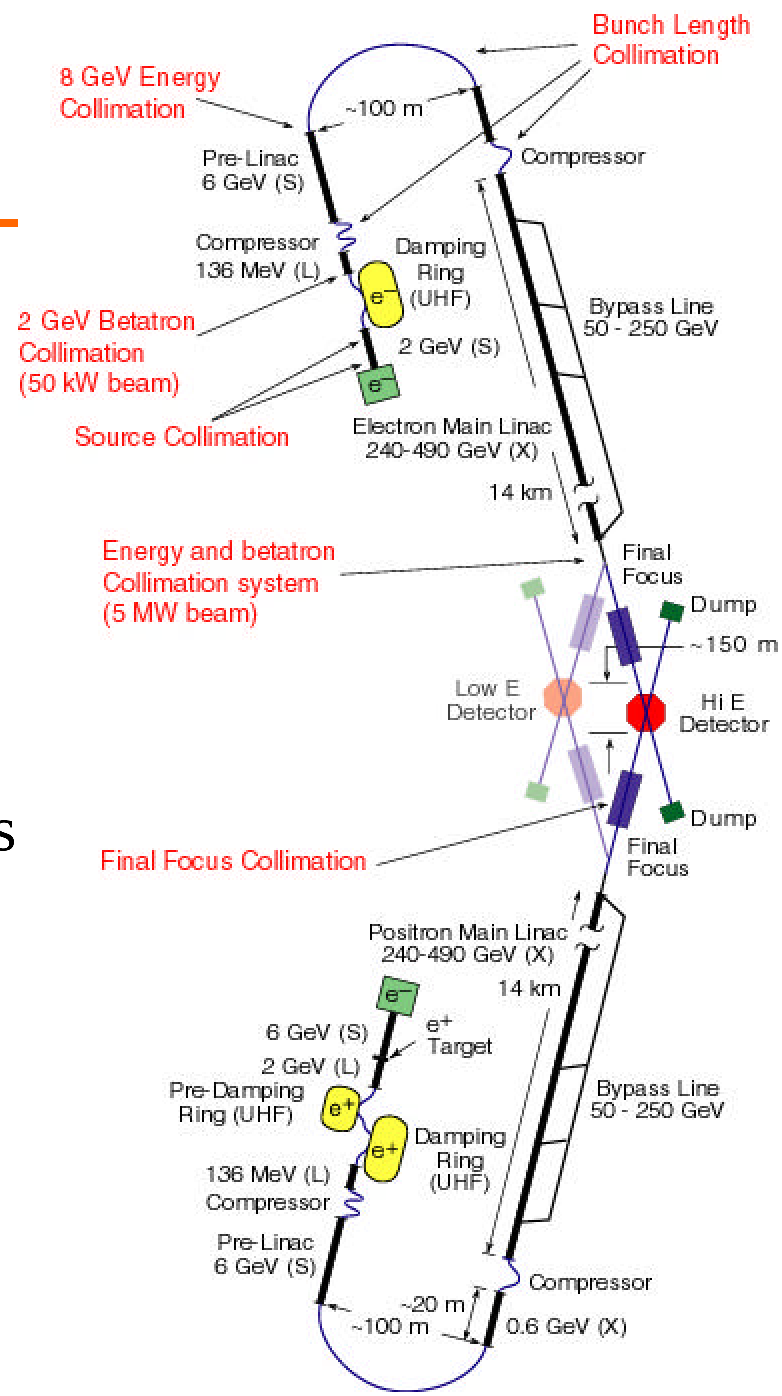
Collimation Issues in e+/e- Linear Colliders

Tor Raubenheimer

SLAC

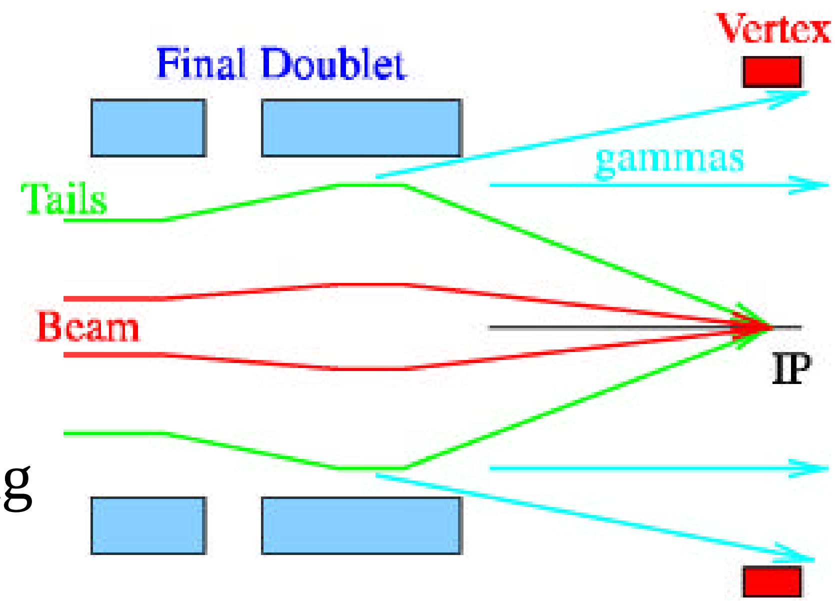
Outline

- Collimation requirements
  - Background reduction
  - Machine protection requirements
- Halo generation
  - Calculations
  - SLC observations
- Collimation damage and wakefields
  - Damage measurements and theory
  - Wakefield measurements and theory
- Present solution
  - Consumable collimators
  - Octupole tail folding
  - NLC baseline



Collimation System Requirements (1)

- Prevent large amplitude particles from showering or radiating photons into the IR
  - In present design, this sets a limit on the angular divergence of roughly 300 x 1000 μrad at the IP ($10\ \sigma_x$ by $31\ \sigma_y$)



Beam halo produces background in the vertex detector

- Collimate tails without generating large muon flux at the IP
  - Limit FFS collimation to a few 10^4 particles
  - Use primary collimation system well upstream of FFS and place muon spoilers downstream
  - Tom Markiewicz will discuss muons Thursday afternoon

Collimation System Requirements (2)

- Protect Damping Rings (DR) from incoming beams
  - 50 kW sources with messy beams
  - DR injection limited by dynamic aperture and large longitudinal mismatch (10:1) – 10% losses at best in SLC e+ damping ring
  - Beams are large → relatively easy collimation and MPS
  - Will not be discussed further here

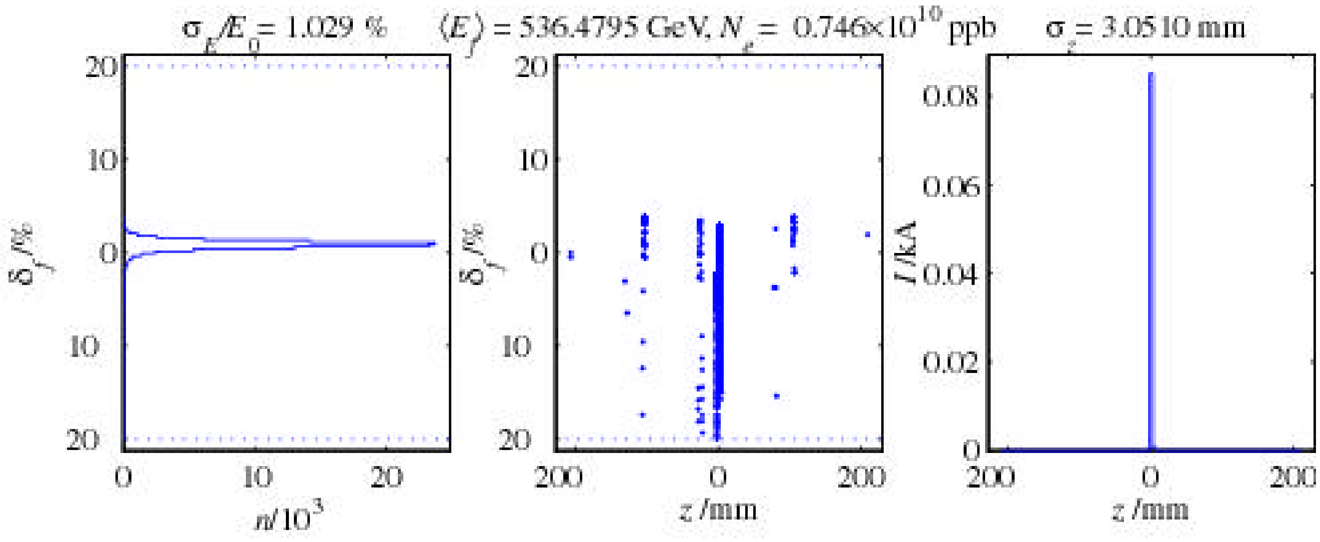
- Protect collider from errant beams (Machine Protection)
  - Linacs are pulsed
    - Frequent energy errors due to phase or voltage errors
    - Need energy protection that can survive repeated beams
  - Most β-tron errors are (by design) slow to develop
    - Limit speed or amplitude of correctors
    - Monitor beams pulse-by-pulse at 120 Hz repetition rate

Halo Generation (1)

- Damping ring
  - Touschek/IBS and beam-gas scattering and nonlinearities will fill transverse and longitudinal phase space (~10^{-4} of the beam)
  - Parasitic bunches from the sources or diffusion between rf bucket
- Transverse wakefields
  - Deflect parasitic bunched or long beam tails to large amplitudes
    - A β-oscillation will increase amplitude of 5 σ_z particles by a factor of 2
    - Could be 10^{-5} of the beam but unlikely
- Scattering
  - Beam-gas scattering in the main linac and BDS
  - Scattering off thermal photons
  - Contributes tails that are 10^{-8} of the beam
- Based on calculation, the tails should be less than 10^{-5} of the beam assuming the DR tails are collimated before the linac

Longitudinal Tails

- Multiple rf frequencies
  - NLC damping rings and SHB at 714 MHz
  - BC1, Prelinacs, and BC2 at 1.4, 2.8, and 11.4 GHz
- Touschek and inelastic scattering will populate longitudinal tails
  - Fully populate the longitudinal bucket
  - Spill over into adjacent buckets



Halo Generation (2)

- In the Stanford Linear Collider (SLC), the tails were as large as 1% but were 0.1% when running well
- Many known SLC sources are less important in NLC
  - Effect of transverse wakefield on the beam is 4x smaller in NLC
  - SLC damping ring had known parasitic bunches from injection mismatch, Touschek scattering, and sub-harmonic buncher
  - SLC bunch compressor had large nonlinearities
- SLC collimation was performed much closer to the beam core: 5 σ_x and 8 σ_y versus 10 σ_x and 31 σ_y
  - Relevant for some processes
- Concern that we missing are missing an important source!
  - Presently designing for tails of 10^{-3} (conservative, we hope)

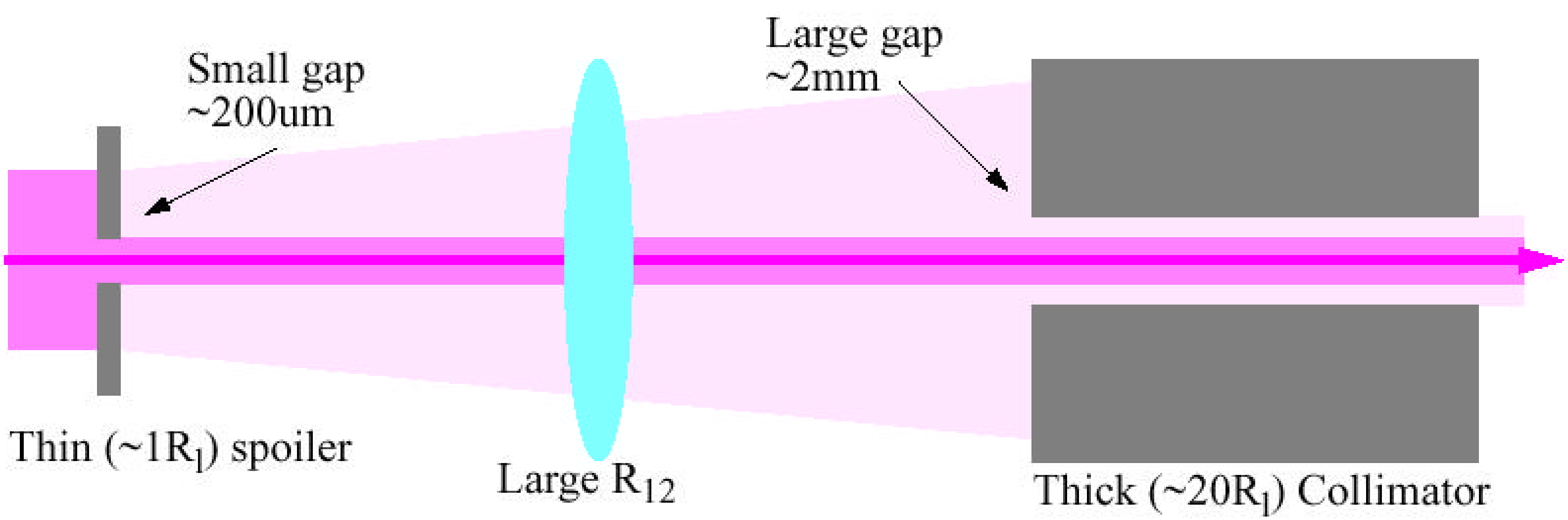
Collimation Difficulties

- Nominal bunch train of 1.5×10^{12} will damage most materials
  - Typical linac beam sizes are 10 x 1 μm
  - Initial damage due to dE/dx (independent of beam energy)
    - Sets a limit on the entrance spots size of ~ 100 μm for Ti and 300 μm for Cu
  - Need much larger spot sizes to absorb full energy beam (about a factor of 10)
  - Spoiler (0.5 r.l.) survival for train requires >100 km beta functions

- Transverse wakefields from collimators scale as $g^2 \sim g^3$
  - Typical linac beam sizes are 10 x 1 μm and collimation needs to be at 10 σ_x and 31 σ_y
  - Scaling of wakefield jitter amplification is roughly independent of the gap but the alignment tolerances scale roughly linearly with g

Spoiler/Absorber Scheme

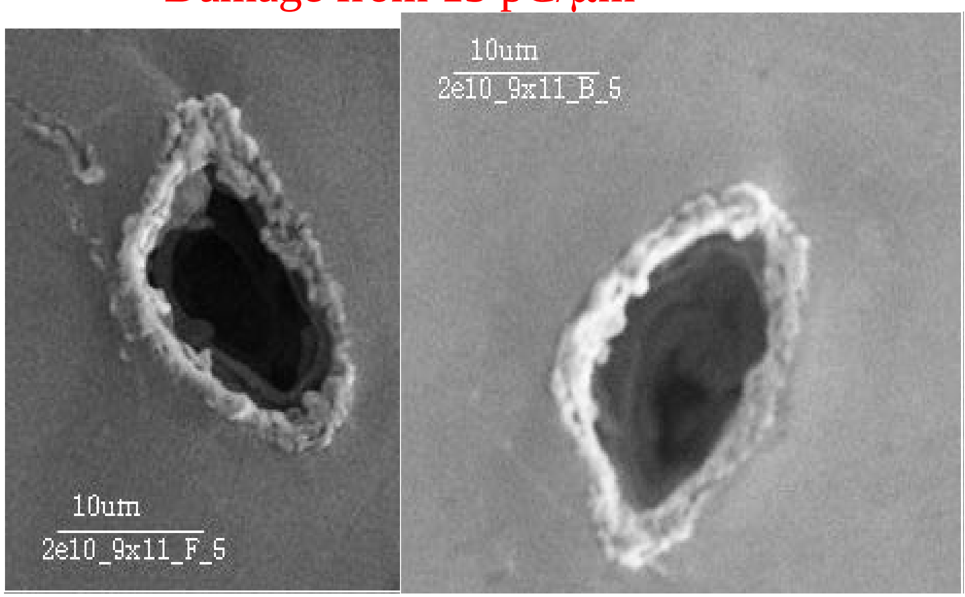
- To reduce wakefields and damage limits
  - Thin spoiler close to the beam scatters the tails and decreases the density of an incoming errant beam
  - Spoiler energy absorption is low (few Watts)
  - Thick absorber can be further out to reduce resistive wakefields
  - Beam power is dumped into absorber

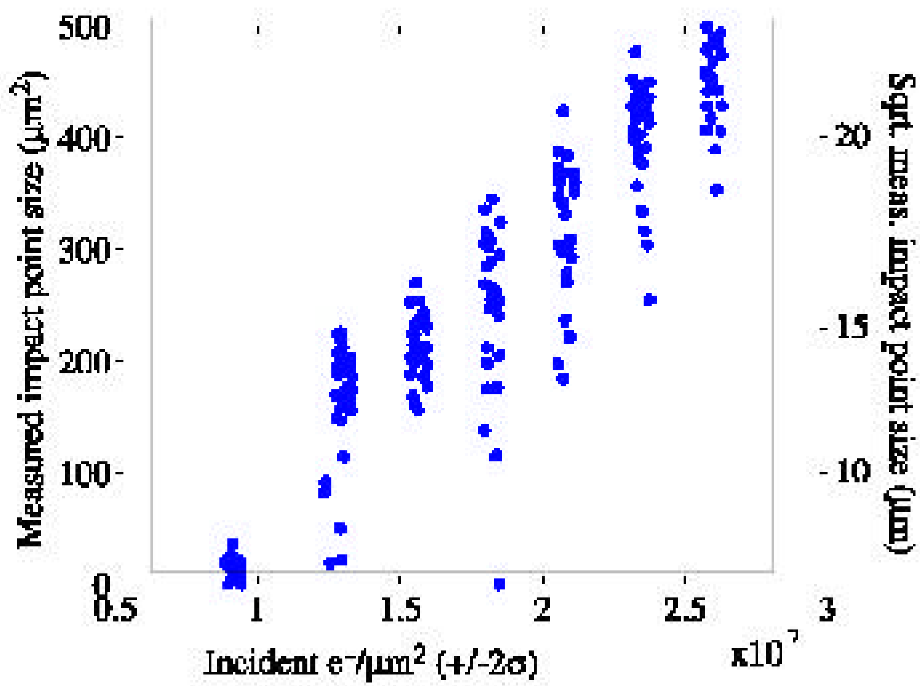


Material Damage

- Three different damage mechanisms
  - Shower absorption – important in thick absorbers
  - dE/dx – important at all length scales
  - Image current – does not require interception
- Studies show single pulse damage consistent with melting
  - Stress limit ~100x times lower

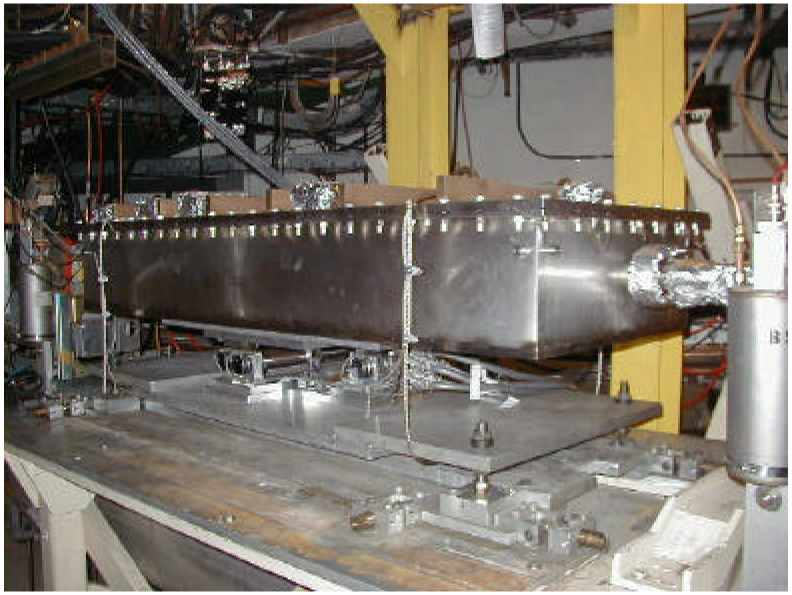
Damage from 13 pC/μm^2



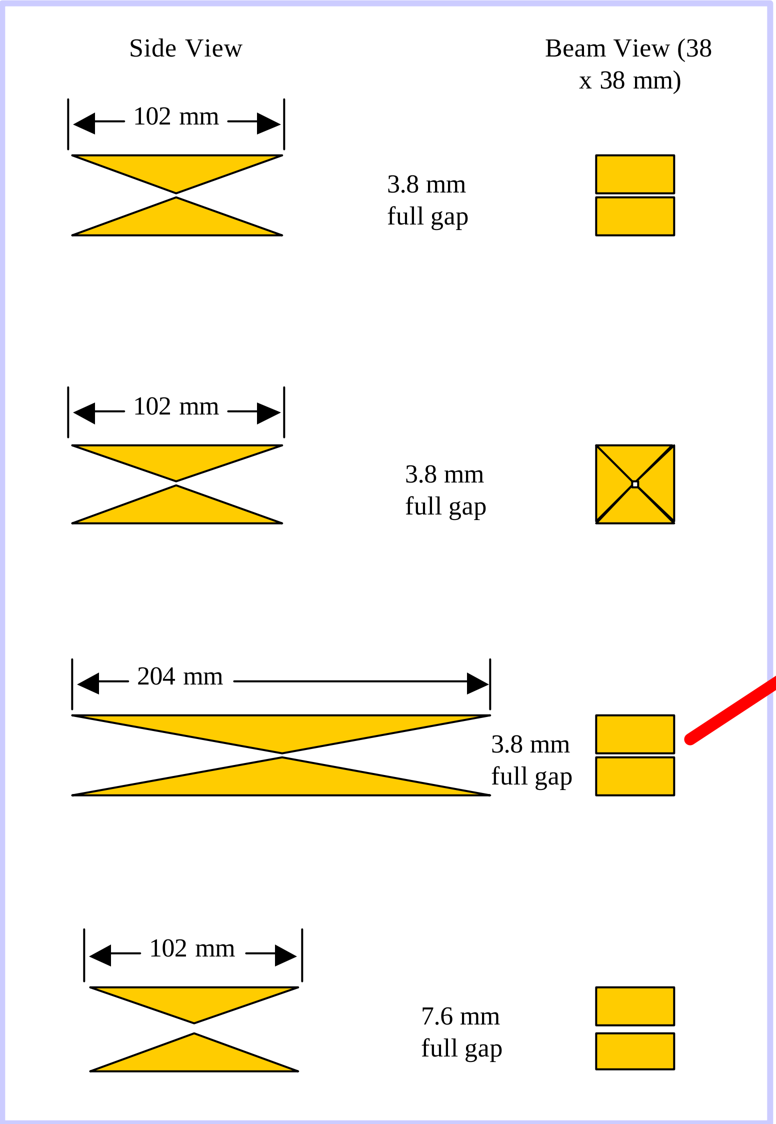


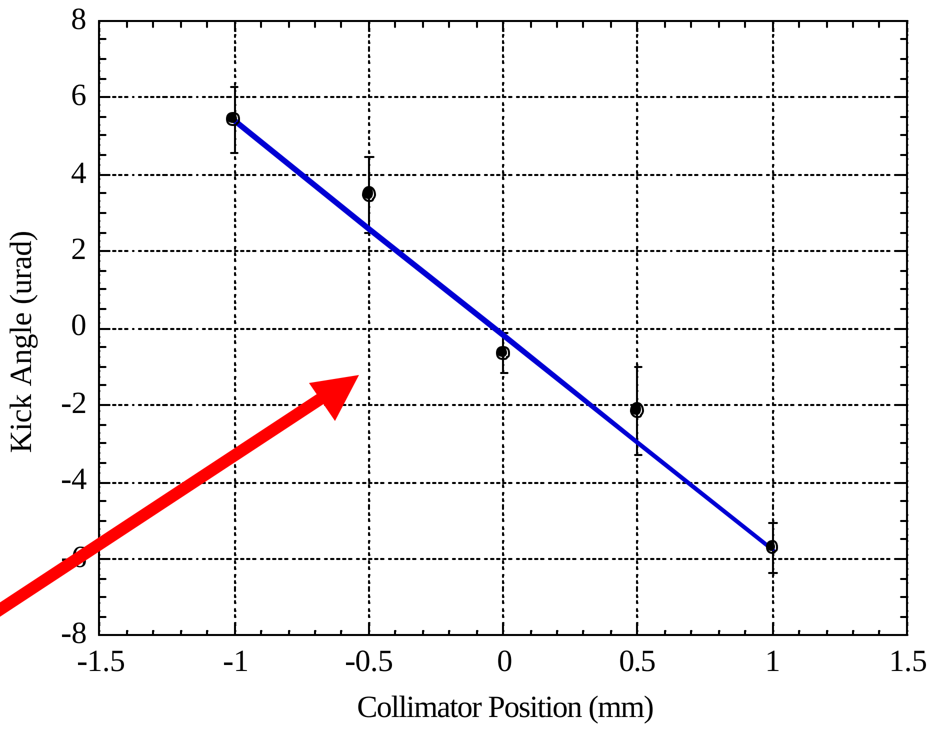
Collimator Wakefields

- Wakefields from rectangular collimators with shallow tapers are difficult to model and difficult to calculate
  - Constructed facility to verify basic theory
  - Measured a copper insert to study geometric wakefields and a graphite insert from DESY to study its properties
  - Will measure a Cu / Ti insert to measure resistive wakes and another Cu insert with geometry closer to NLC specs
  - Each insert has four collimators plus an unobstructed aperture
  - After correction of theory, factors of two difference
  - Comparison with MAFIA / τ3P is very good



Collimator Wakefield Measurement





Peter Tenenbaum will discuss measurement and theory Thursday afternoon

Collimator Wakefield Measurement

Rectangular Collimators:

Width

Long Taper:

$$\frac{y'}{y} = \frac{\sqrt{p}}{2} \frac{Nr_e}{g} \frac{hq_{taper}}{r_1^2 s_z}$$

Gap

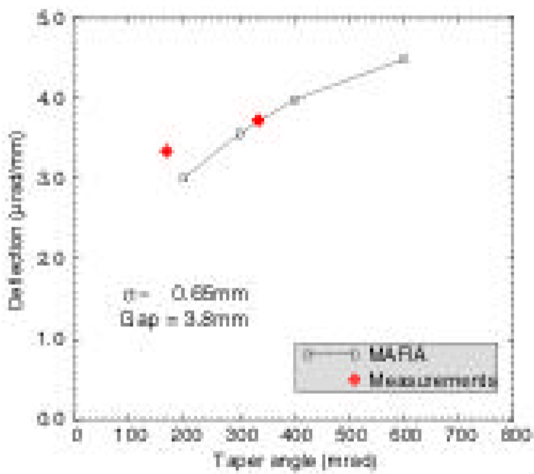
Applicability: h² ?$_{taper}$/(s$_z$r$_1$) <<1

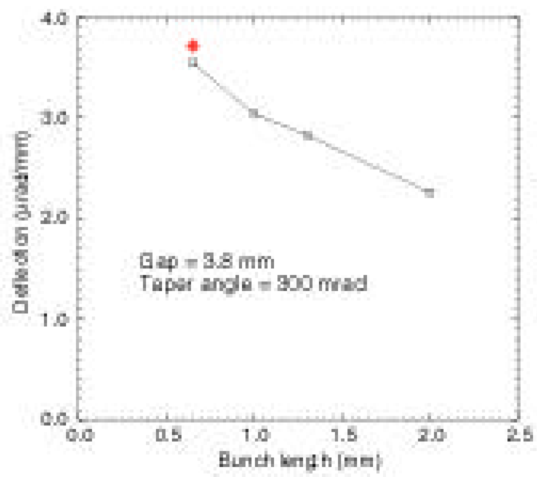
Short Taper:

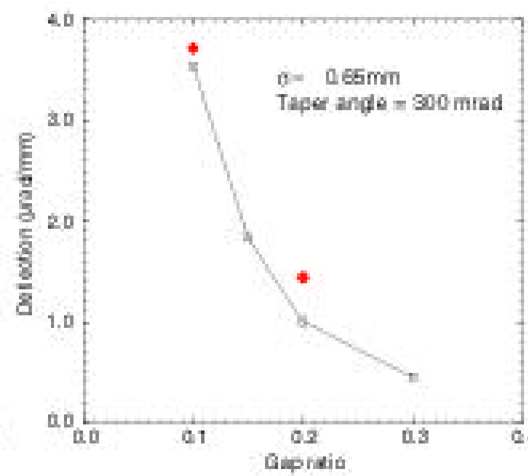
$$\frac{y'}{y} = \frac{Nr_e}{g} \frac{1}{r_1^2}$$

Applicability: ?$_{taper}$r$_1$/s$_z$ >> 1

Spoiler taper angle is chosen to balance resistive vs. geometric wakefields







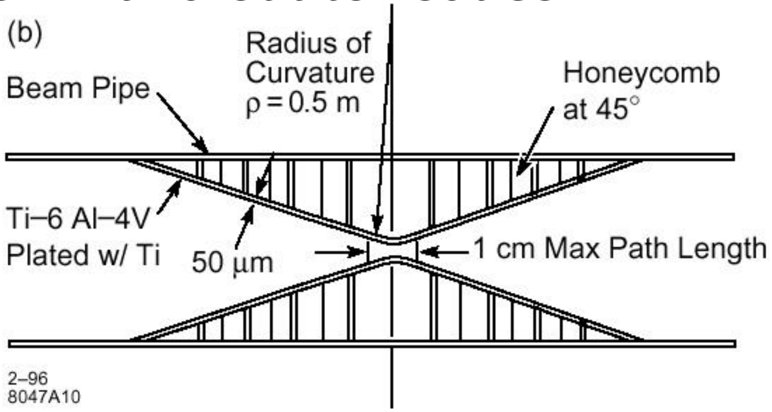
Consumable Collimators

- Transverse trajectory errors are relatively infrequent or sufficiently slow so that they can be caught by monitoring
  - Estimate less than a 100 per year
- Passive survival of spoilers require >100 km β-functions
  - Lattice is highly chromatic and very sensitive to errors
  - Creates more problems than solves

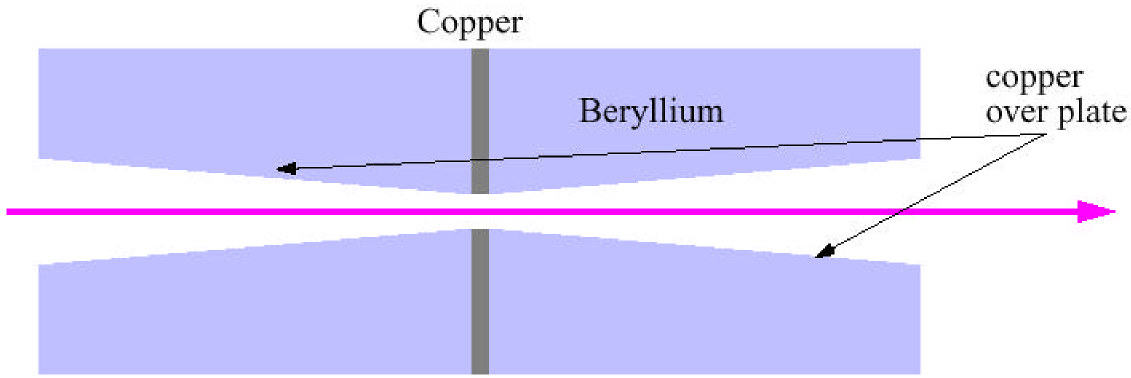
- Design collimators to allow a certain amount of damage
  - Consumable collimators can be rotated to new surface after being damaged
    - Seems likely possible – 1st prototype to study mechanics
  - Renewable collimators would generate new surface on every pulse
    - Liquid metals – looks difficult!

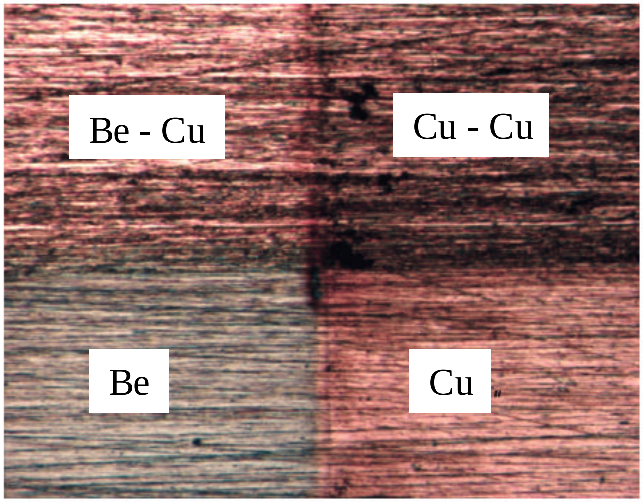
Consumable Collimator

- Want thin spoiler but need long taper in and out to reduce geometric wakefields
  - 1996 concept was to use titanium honeycomb

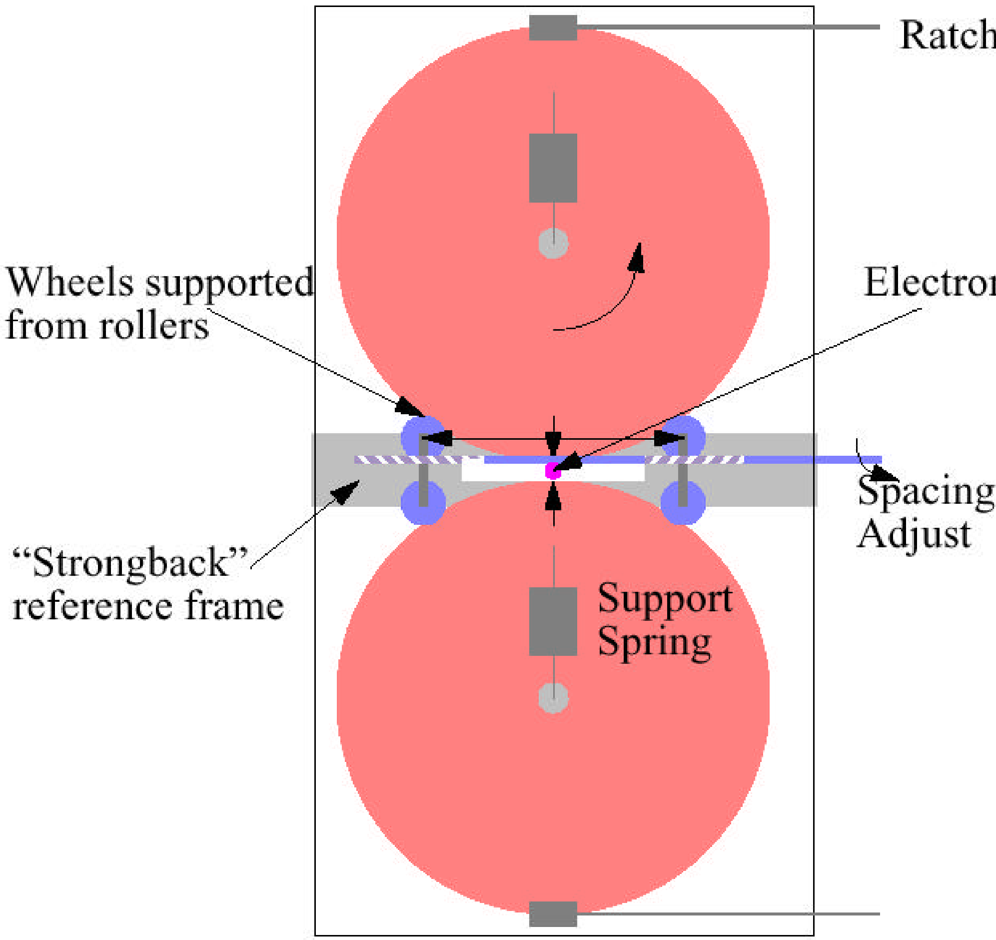


  - Present concept is to use beryllium to taper in and out
    - Probably coat Be with 1µm of Cu



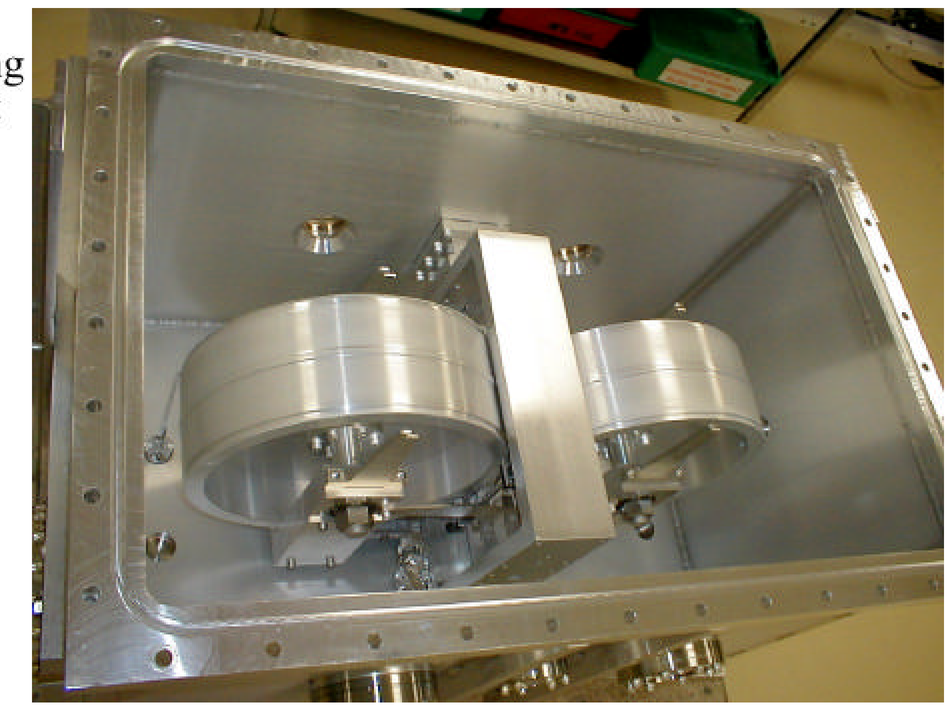


Consumable Collimator Prototype



Prototype demonstrates basic performance

Tom Markiewicz will describe this system Thursday afternoon

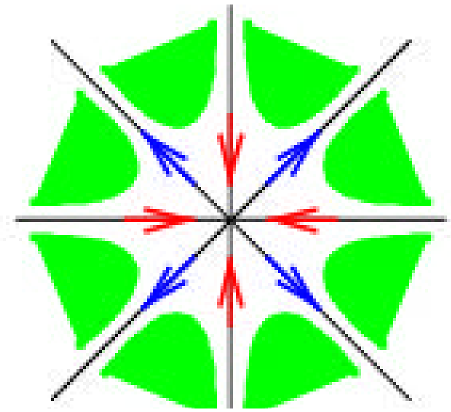


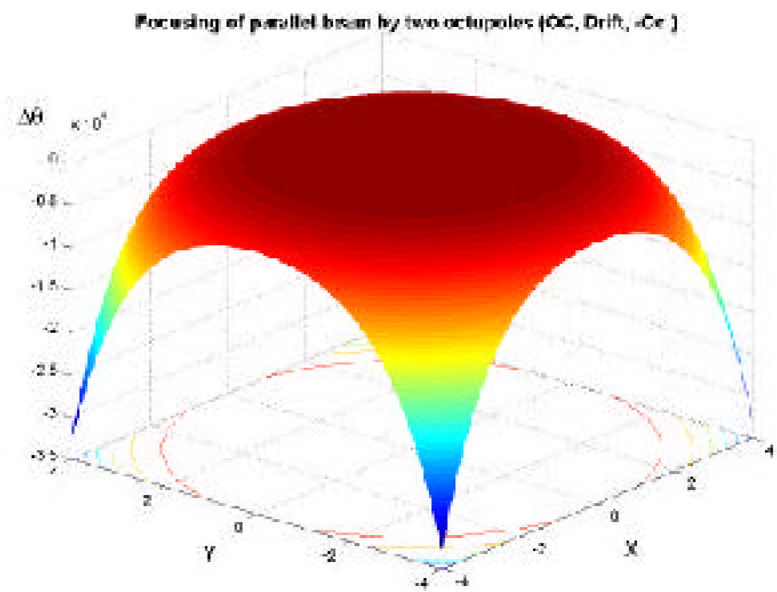
Octupole Tail-Folding

- One wants to **focus beam tails** leaving the core of the beam unchanged
  - use **nonlinear** elements (e.g. octupoles)

- **Several** nonlinear elements needed to provide **focusing in all directions**
  - Similar to **FODO** strong focusing

- A very simple and elegant solution is to use **Octupole Doublets (OD)**
  - **An octupole focuses along the X and Y axes and defocuses on the diagonals.**
  - **An octupole doublet can focus in all directions !**

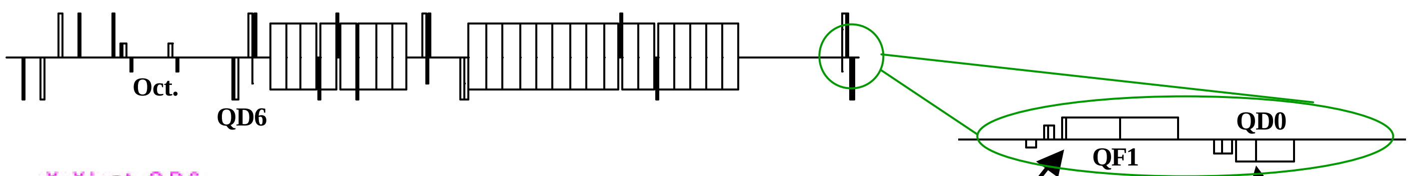


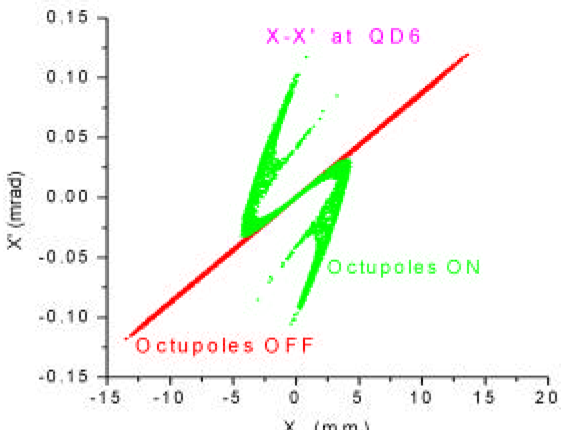


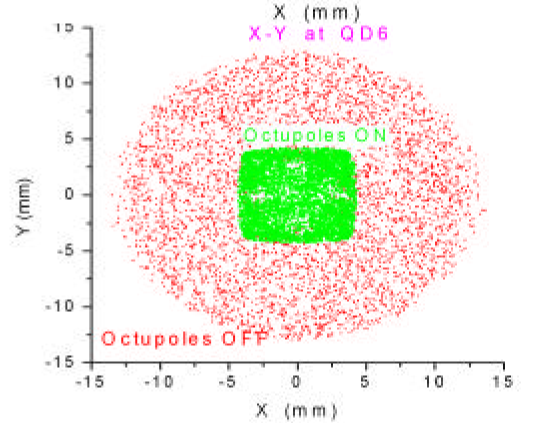
Effect of octupole doublet (Oc,Drift,-Oc) on parallel beam, DQ(x,y).

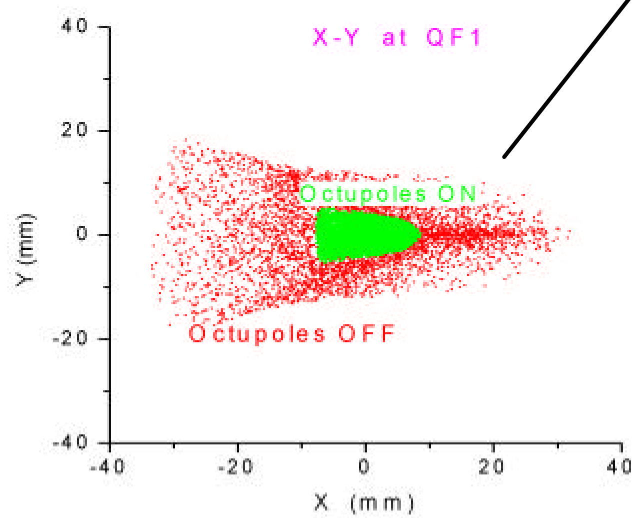
Tail folding in new NLC FF

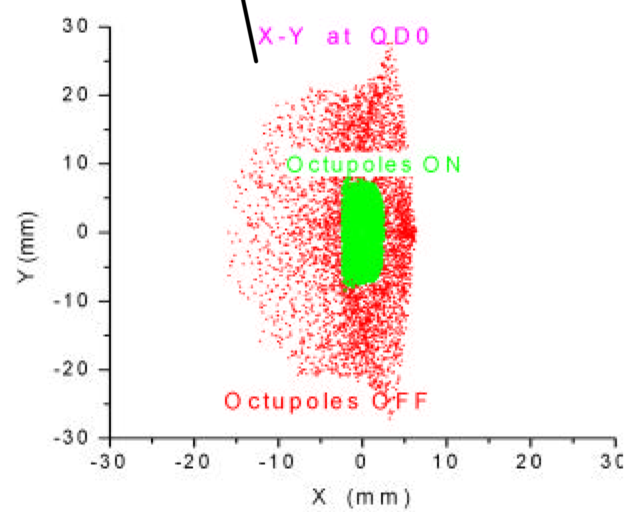
Two octupole doublets can relax collimation requirements by ~ a factor of 3





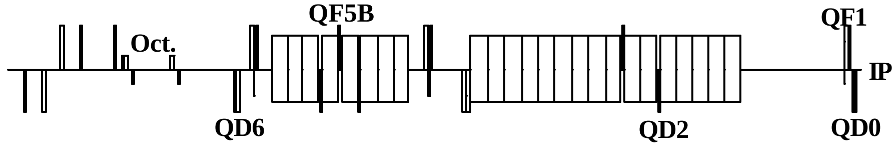




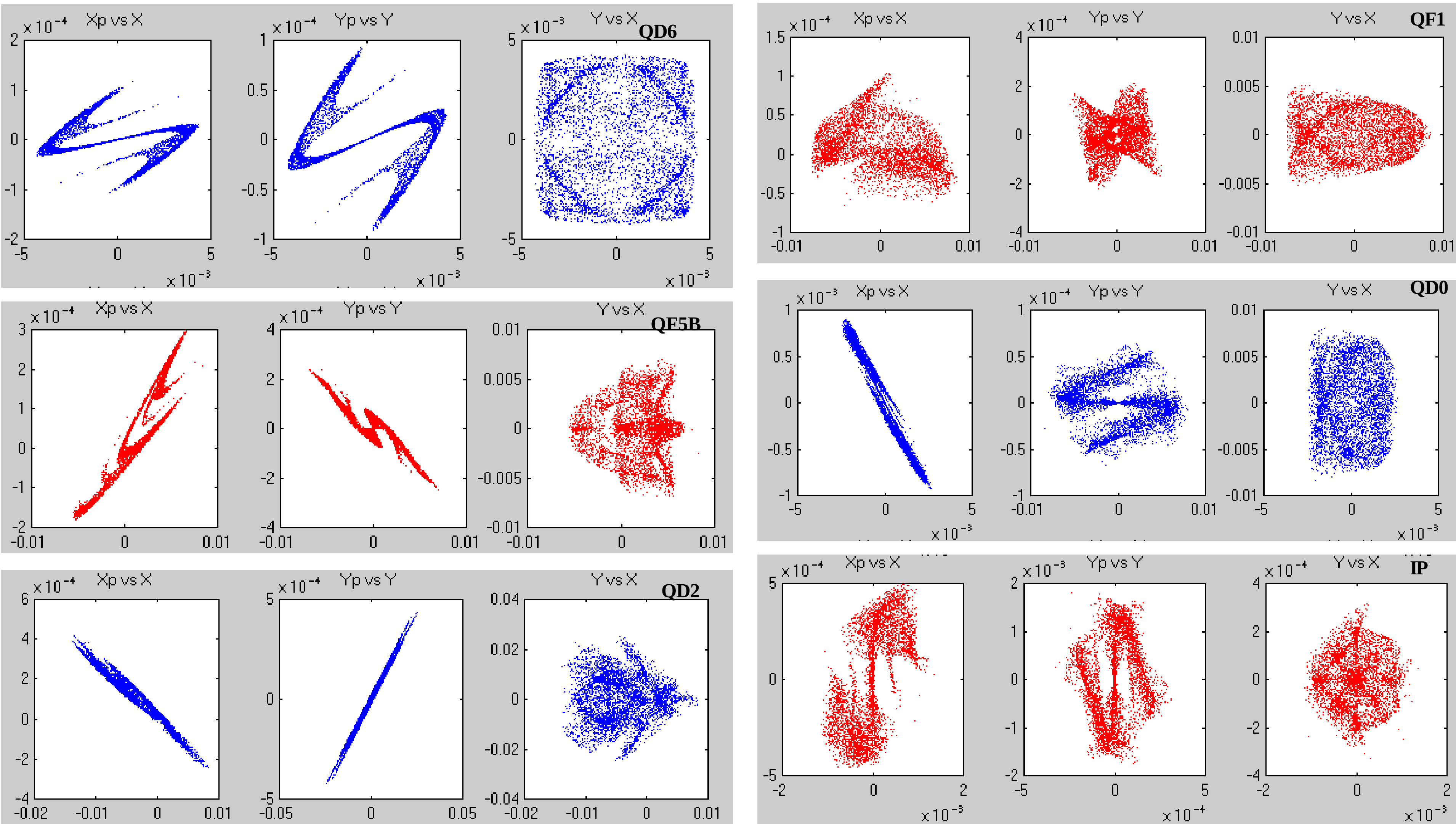


Input beam has (x, x', y, y') = (14µm, 1.2mrad, 0.63µm, 5.2mrad) in IP units (flat distribution, half width) and ±2% energy spread, that corresponds approximately to N_σ=(65, 65, 230, 230) sigmas with respect to the nominal NLC beam

Tail folding
or Origami Zoo

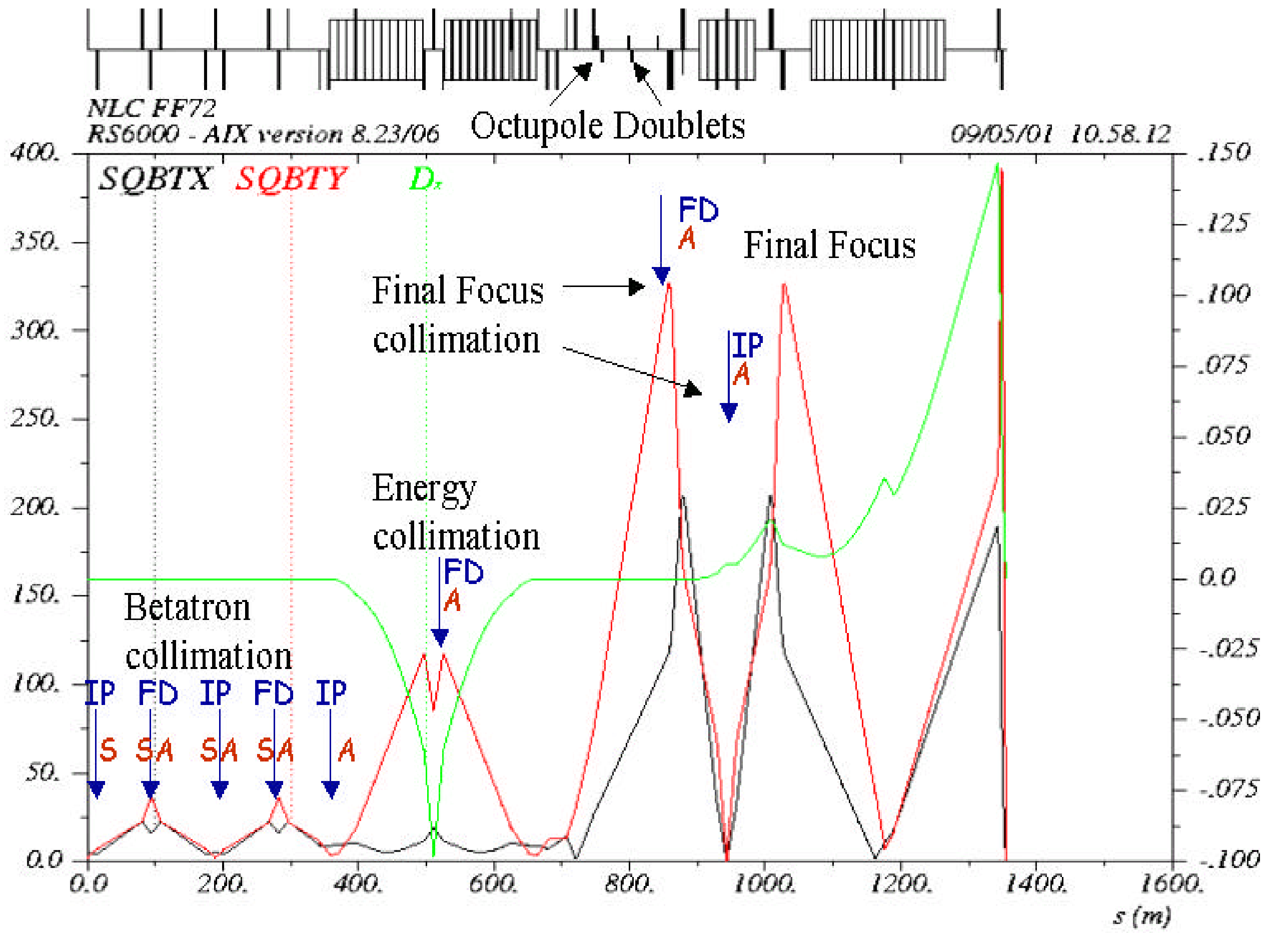


Andrei Seryi will discuss the octupole tail-folding in detail this afternoon



BDS Collimation System

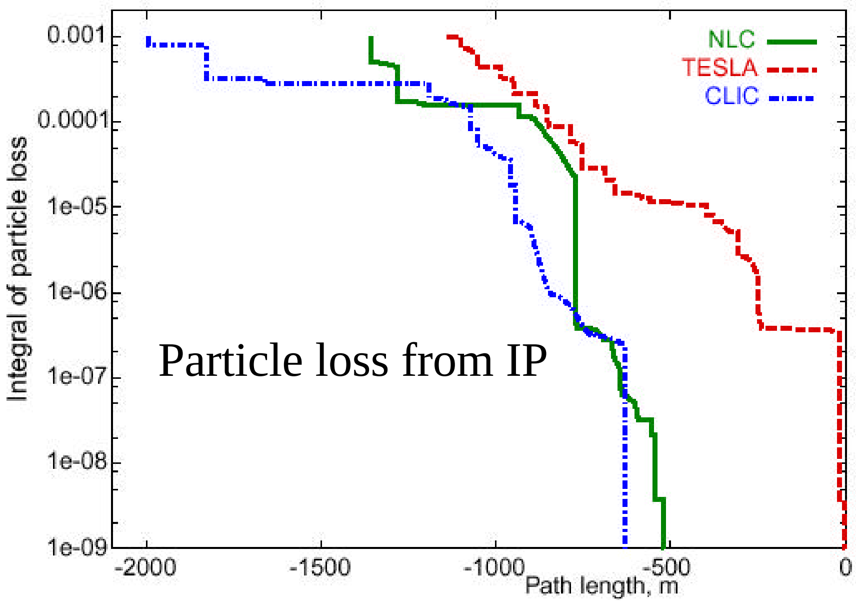
- Collimation system has been built in the Final Focus system
- Collimators optimized for octupoles off and then relaxed with octupoles off
- Two octupole doublets are placed in NLC FF for active folding of beam tails
- Gives tail folding ~ 3 times in terms of beam size in FD

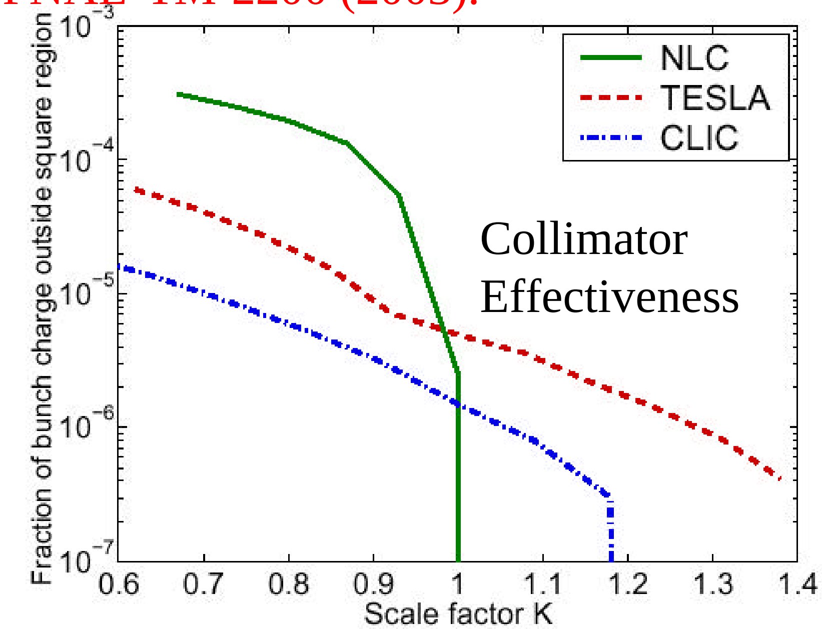


Collimation depth: 10 σ_x, 31 σ_y, 1.5% $\sigma_{\Delta E/E}$

BDS Collimator System

A. Drozhdin, et al, FNAL-TM-2200 (2003).





Jitter amplification

	TESLA			NLC			CLIC		
Parameter	$\mathcal{A}_x$	$\mathcal{A}_y$	$\mathcal{A}_\delta$	$\mathcal{A}_x$	$\mathcal{A}_y$	$\mathcal{A}_\delta$	$\mathcal{A}_x$	$\mathcal{A}_y$	$\mathcal{A}_\delta$
δ spoilers	0.035	0.054	0.27	0.0010	0.045	0.053	0.0017	0.16	0.049
δ absorbers	0.0063	0.034	0.058	0.0053	0.016	0.019	0.0035	0.37	0.10
β spoilers	0.066	0.55	0	0.081	0.59	0	0.099	1.67	0
β absorbers	0.032	0.51	0	0.0032	0.014	0	0.12	0.33	0
FF spoilers	0.080	0.73	0.019	N/A	N/A	N/A	0.034	0.32	0.13
FF absorbers	0.024	0.38	0.029	0.062	0.53	0.0019	N/A	N/A	N/A
Total	0.24	2.26	0.34	0.15	1.20	0.074	0.26	2.84	0.027

Collimator Settings

Spoiler and absorber settings for octupoles off

		spoilers, absorbers			half-aperture			
S	Name	BetaX	BetaY	Dispers.	A_x	A_y	A_x	A_y
m		m	m	m	mm	mm	σ_x	σ_y
0.007	SP1	35.83	7.07	0.000	0.30	0.25	18.5	326
76.491	SP2	103.28	523.42	0.000	0.28	0.20	10.2	31
152.374	AB3	35.82	7.08	0.000	1.00	1.00	61.5	1304
152.491	SP3	35.82	7.08	0.000	0.30	0.25	18.5	326
228.374	AB4	103.28	523.42	0.000	1.00	1.00	36.3	153
228.491	SP4	103.28	523.42	0.000	0.28	0.20	10.2	31
288.866	AB5	59.74	5.36	0.000	1.40	1.00	66.8	1500
288.983	SP5	59.74	5.36	0.000	0.42	0.25	20.0	375
497.592	SPE	226.69	10058.96	0.213	3.20	3.20	78.3	112
662.449	ABEa	244.35	329.16	0.007	1.10	1.10	25.9	212
664.749	ABEb	240.00	283.52	0.006	1.10	1.10	26.2	228
890.421	AB10	13276.75	149854.87	0.000	4.40	4.40	14.1	40
911.000	AB9	38123.55	55295.79	0.000	6.50	3.00	12.3	45
984.952	AB7	36.63	82.44	-0.026	3.90	1.00	238	385
1384.005	DUMP1	21712.01	30406.34	-0.115	8.00	20.00	20	400
1420.795	DUMP2	33628.04	52550.49	-0.115	8.50	20.00	17.1	303
1433.815	IP							

Summary

- Many issues for collimation in future LC
  - Collimation depth determined by synchrotron radiation from halo into the IR which is more stringent than particle loss
  - Collimation concept based on spoiler—absorber scheme
  - Consumable collimators may handle MPS requirements without undue increase in beam sizes
  - Octupole tail-folding may greatly relax system
  - Collimator wakefields are an important limit
- Seem to have a concept that works but …
- Questions about:
  - Halo/tail sources
  - Materials properties with damage and radiation
  - Real effectiveness of the octupole tail-folding scheme